Steam Stripping/Hydrous Pyrolysis Oxidation for In-Situ Remediation of a TCE DNAPL Spill

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ABSTRACT: A field demonstration of Steam Stripping and Hydrous Pyrolysis Oxidation (SS/HPO) was conducted at the Portsmouth DOE facility in Ohio. A trichloroethene (TCE) release at the site had led to DNAPL concentration in a semi-confined water bearing zone in the overburden, and in the upper part of a bedrock shale layer. It was demonstrated that steam injection can heat the water-bearing zone directly, and that the TCE can be removed effectively from the layers, including the top of the shale layer located below the steam zone. Both direct vaporization and removal of TCE as a vapor, and chemical oxidation contributed to reduction of the TCE source term. More detail is provided in SteamTech Environmental Services (1999).

Bench-scale studies have shown greater than 99% mass removal of TCE from soils during heating, both using direct steam injection and electrical heating to produce steam within the soil itself (Udell 1996; Heron et al. 1998b). During steam stripping, HPO destroys dissolved contaminants in place by utilizing hydrothermal oxidation (Knauss et al. 1997). In a heated, oxygenated zone, contaminants are oxidized and degraded (TCE is converted to carbon dioxide, water, and chloride ions). This study combined lessons learned into one field strategy.

DNAPL TCE was spilled from a holding pond into a relatively permeable sandy aquifer sandwiched between two low-permeability formations (Figures 1 and 2). The groundwater contamination plume extended eastward about 1,900 ft (580 m) from the holding pond, with TCE concentrations as high as 970 mg/L in groundwater samples. DNAPL had penetrated the upper two feet (0.6 m) of the Sunbury Shale, and extended well beyond the demonstration area. This created a unique challenge for the field demonstration, and complete cleanup of the area was not an objective.

Heating the site from below was not possible due to the thickness of the shale. Thus, it was decided that steam injection into the sand-dominated lower Gallia formation was the best approach. A ring of 7 outer injection wells and four central extraction wells were installed (Figure 1). In addition, due to the relatively low permeability of the target area, three multi-purpose wells were installed and used both for extraction and steam injection. Finally, after a cold water channel was identified through detailed geophysical monitoring, six additional steam injection wells were added to the well-field, for improved heat-up during the final month of operation.

Steam was injected into a total of 16 wells at typical rates of 50 to 600 lbs/hr (23-280 kg/hr) per well, with a total injection rate of between 1,500 and 5,500 lbs/hr. A total of approximately 4 million liters of water was injected as steam. In the same period, 6.5 million liters of water was extracted from the center of the site, ensuring hydraulic control. The aggressive vacuum extraction system recovered 1.6 million kg of vapors, at the applied vacuum of between 6 and 18 in Hg (200-600 mbar).

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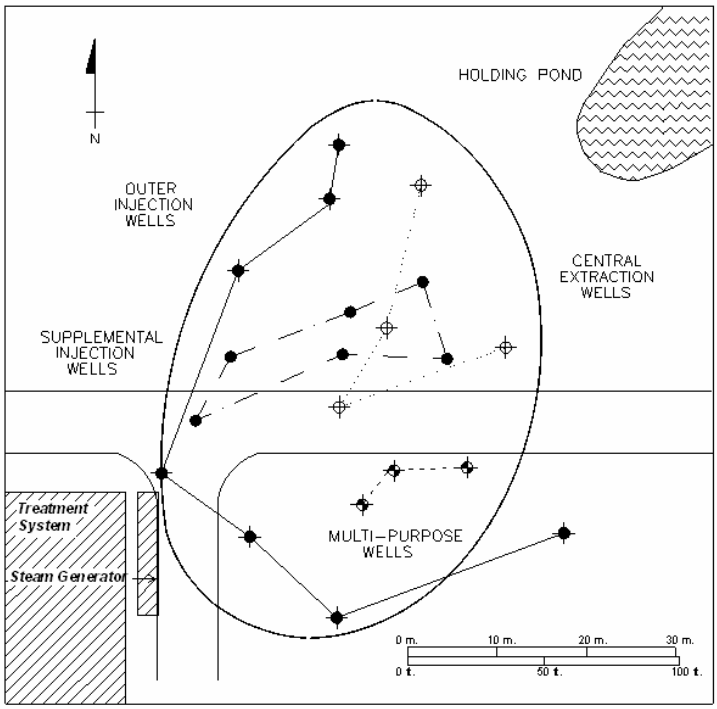

Figure 1. Site map and well-field layout for the SS/HPO demonstration at PORTS. The holding pond to the northeast is the source of the contamination. The TCE plume extends 1,900 ft to the east of the holding pond.

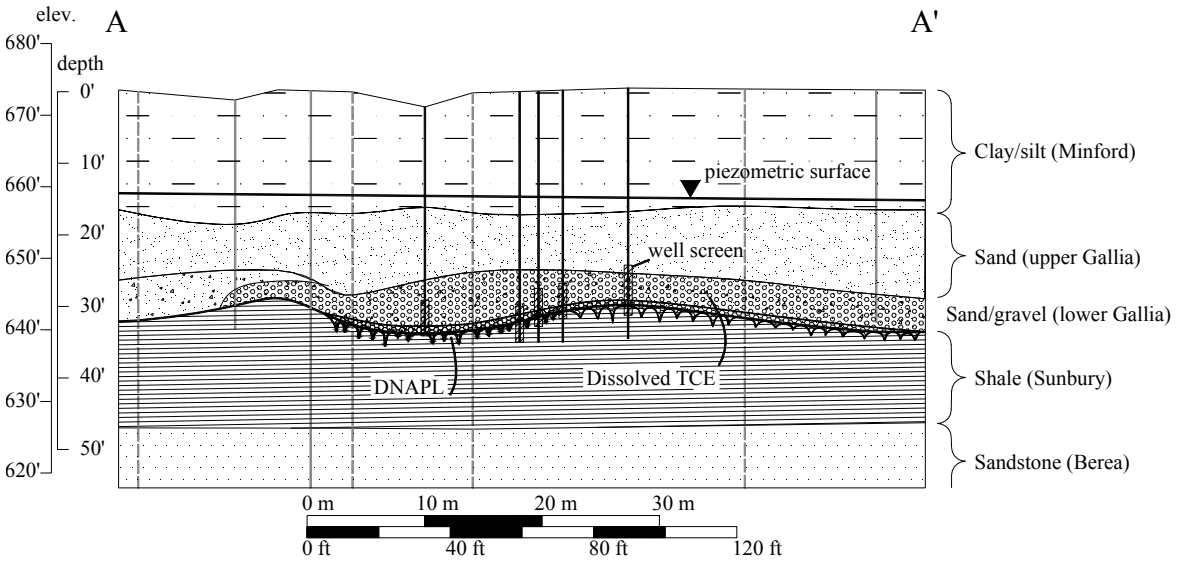

Figure 2. West-east cross-section through the demonstration area with the interpreted DNAPL distribution and location of example wells screened in the lower Gallia.

The heat-up was monitored in detail using thermocouples and Electrical Resistivity Tomography (ERT). As predicted, the steam migrated in the lower Gallia, without significant steam penetration directly to the lower Shale or the upper silts and clays. After approximately 3 months

of operation, the target lower Gallia and the upper two feet of the Sunbury Shale was heated to the desired temperature. After this, one month of cyclic steam injection and air co-injection was conducted in order to accelerate the TCE removal and destruction.

The main removal mechanism is TCE DNAPL boiling and vaporization in places heated to temperatures above the in-situ boiling point. Where DNAPL is present, this temperature is approximately 72 ^{o}C, the eutectic temperature (Heron et al. 1998a). At this temperature, the vapor pressure of the water plus the vapor pressure of the TCE add up to one atmosphere, and boiling occurs. As the vapors migrate up and into the steam zone, they are flushed along with the steam towards extraction wells.

A total of about 400 kg (830 lbs) of TCE was removed from the subsurface during operations. During the last month of operation, air was injected with the steam to stimulate HPO reactions. The carbon dioxide concentrations in the extracted vapors rose from around 330 ppmv (background) to between 1,400 and 2,000 ppmv. This is an indication of TCE mineralization, producing carbon dioxide and calcite. Drill-back revealed that the target layer has been largely remediated, leaving relatively low TCE soil concentrations behind. Three-dimensional kriging of all the collected soil concentrations indicated that total masses of 550 kg (1,200 lbs) and 115 kg (247 lbs) were present in the demonstration volume pre- and post the SS/HPO demonstration, respectively. These numbers agree well with the recovered TCE mass.

Overall, it was concluded that SS/HPO is a viable technology for removal of TCE DNAPL from the semi-confined water bearing zone as well as the upper, relatively impermeable Sunbury Shale. This pilot test showed that if operated longer, TCE can be effectively removed to low residual levels in soils and groundwater, even when more than half of the mass is trapped below the permeable aquifer in weathered, fractured shale. TCE is removed both by vaporization and extraction, and by in-situ destruction at the elevated temperatures

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